
CERN

Nb_3Sn RRP 108 Wire
Beam Impact Damage Study

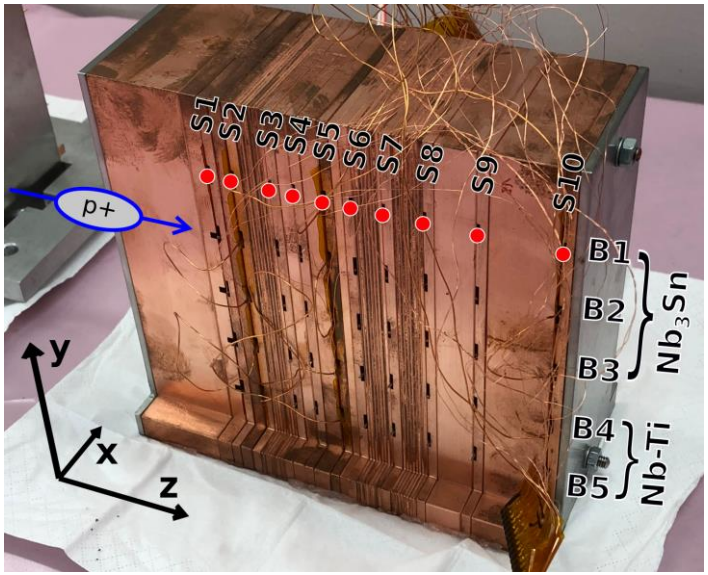
Presenting: Jonathan Schubert
Supervisor: Andreas Will
Daniel Wollmann

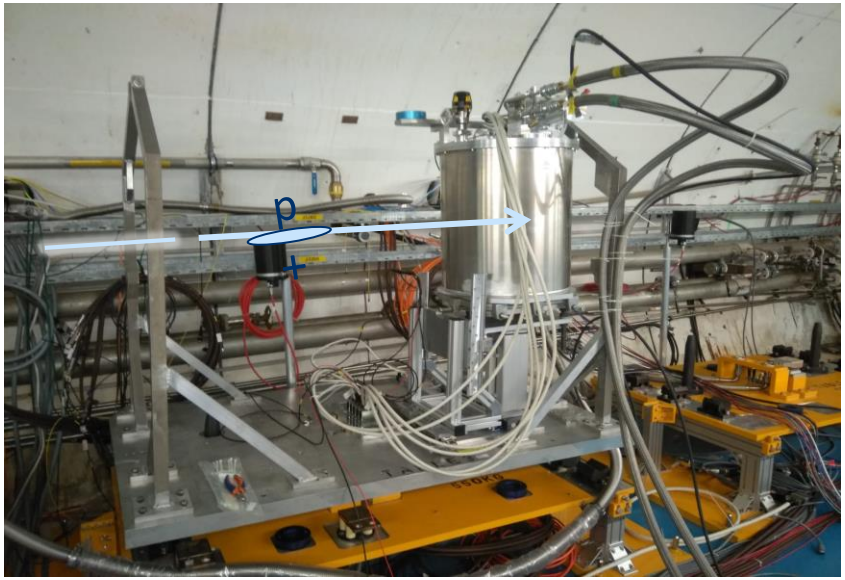
What I want to talk about

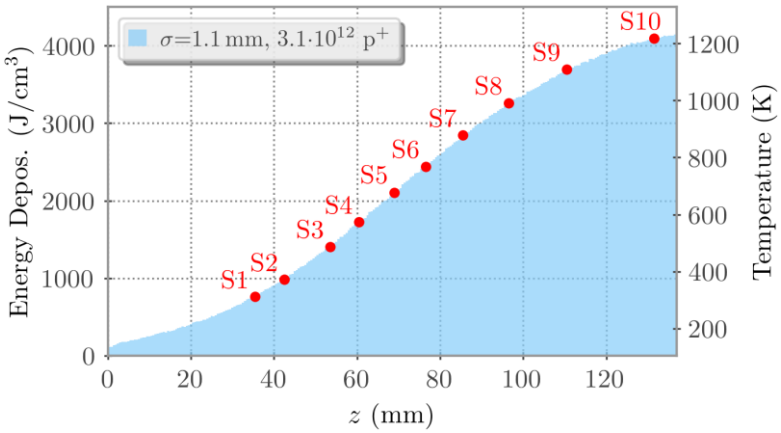
- A brief reminder of what we work on
- Simulation Workflow
- Results
- Summary

A brief reminder of what we work on

Beam Impact studies on Superconductor Strands at 4K





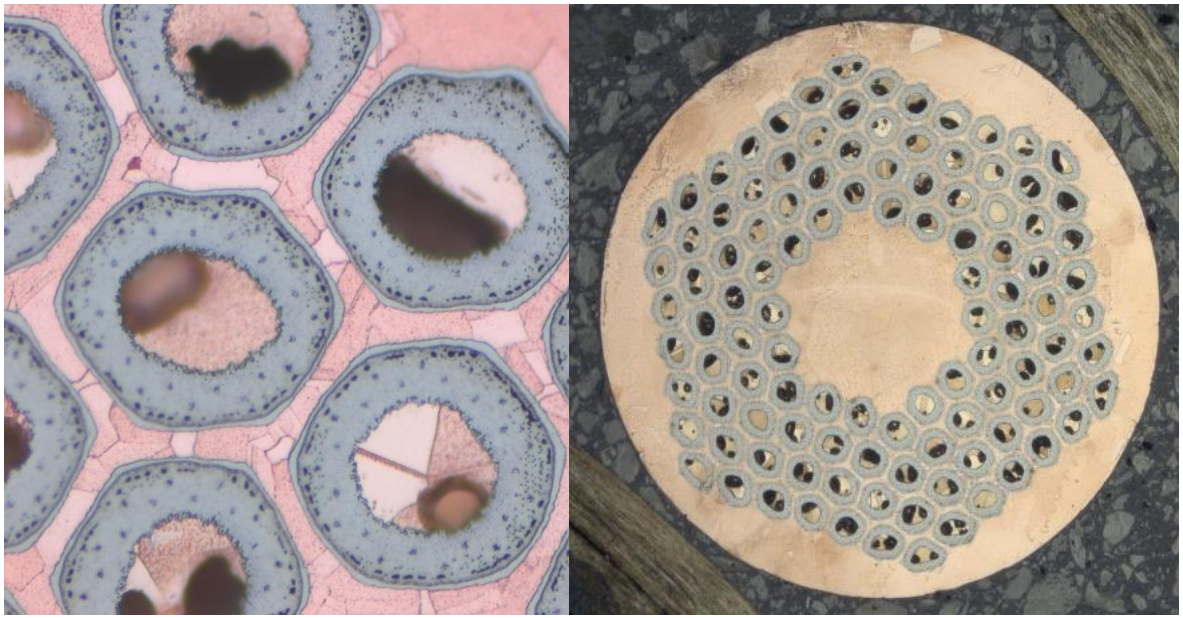


A brief reminder of what we work on

My work focused on:

Nb_3Sn strand (HL-LHC)

50 mm, Ø 0.85 mm



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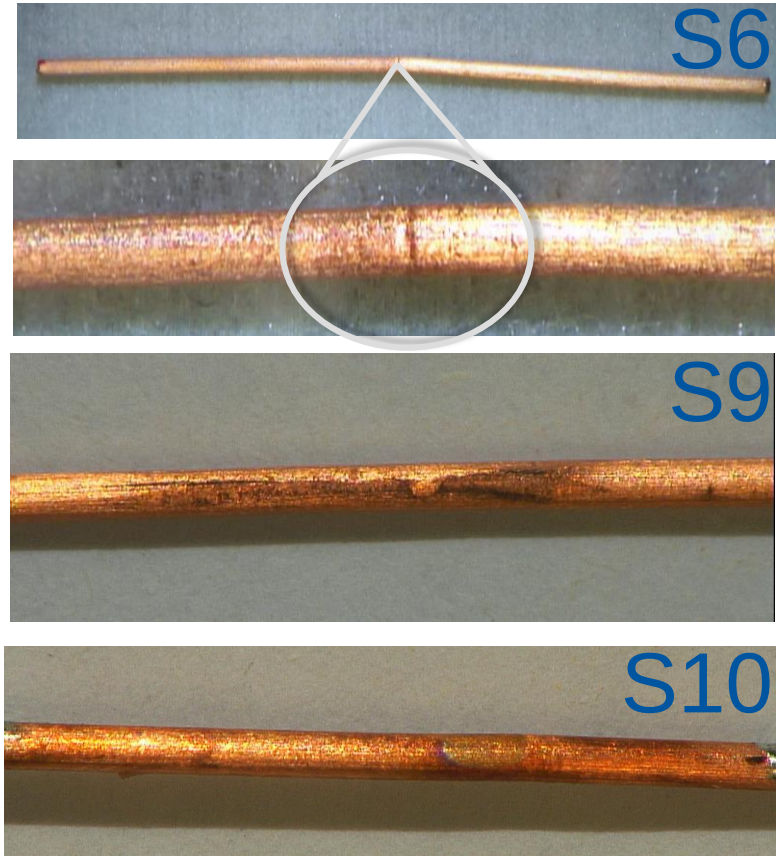
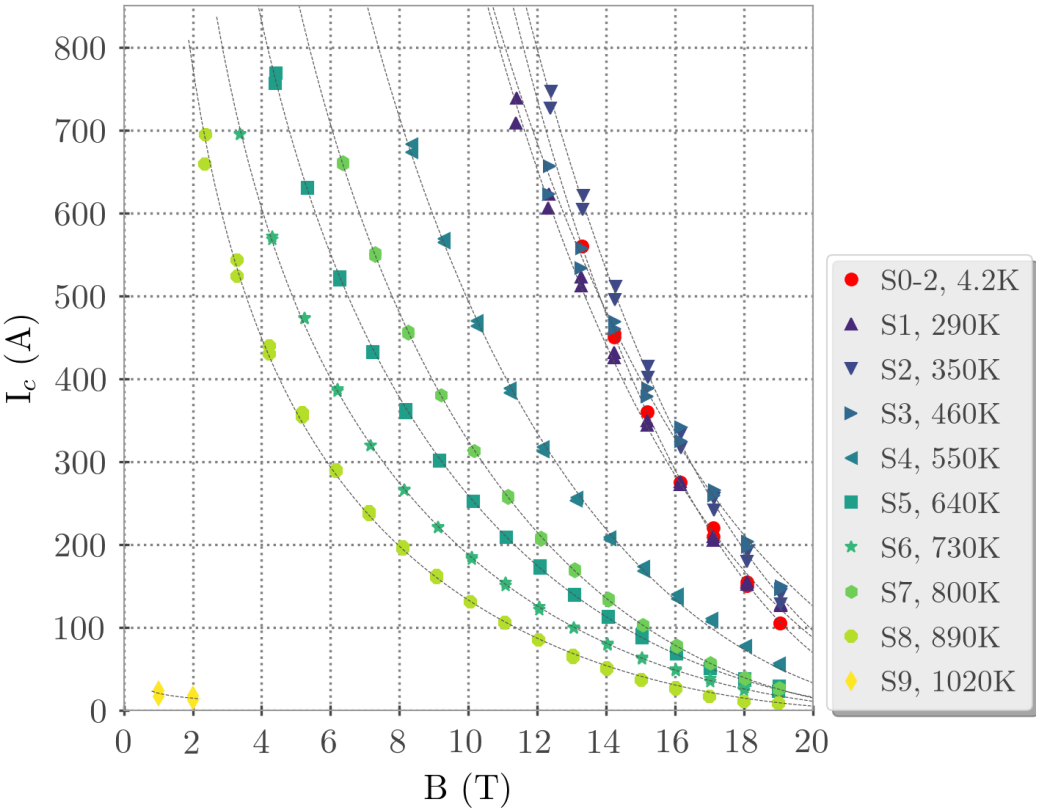




Simulating the Impact

The general idea / workflow pipe

Energy Depostion

Thermal Evolution

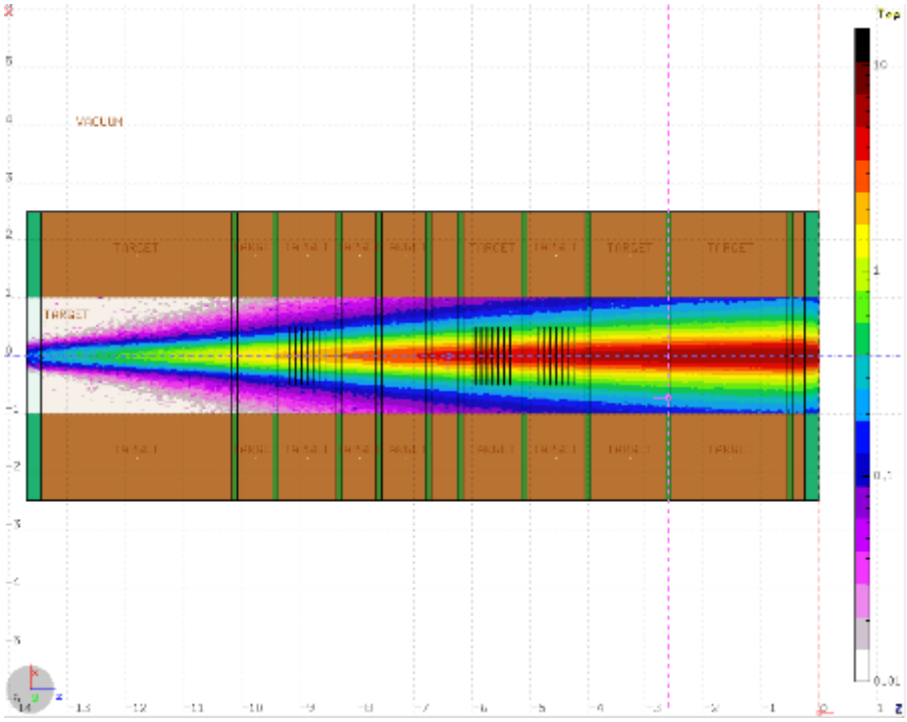
Mechanical response

Theory based Evaluation

Energy Deposition

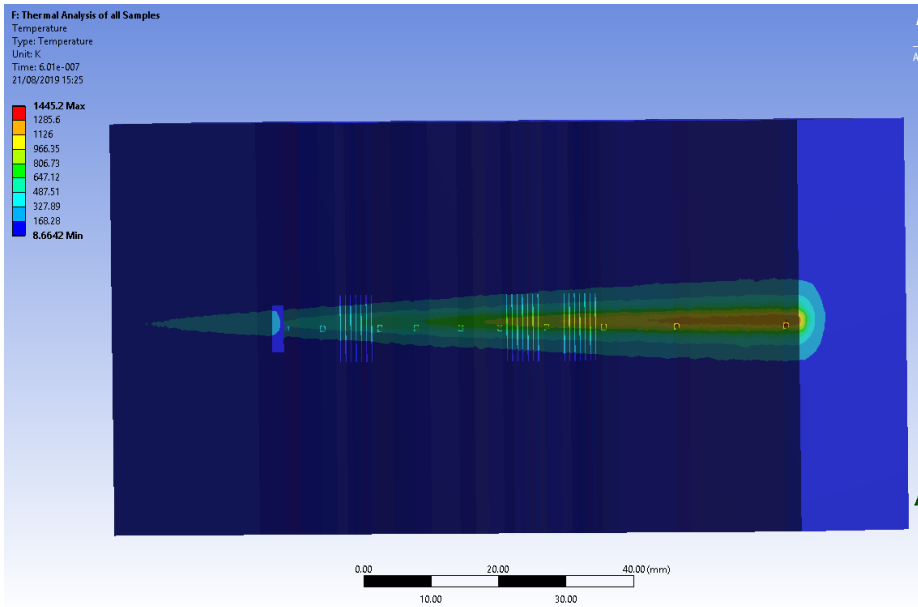
Generating a probabilistic Energy Deposition Map per Primary Particle

Scaling the Energy with the Beam Signature to get an on/off heating Rate

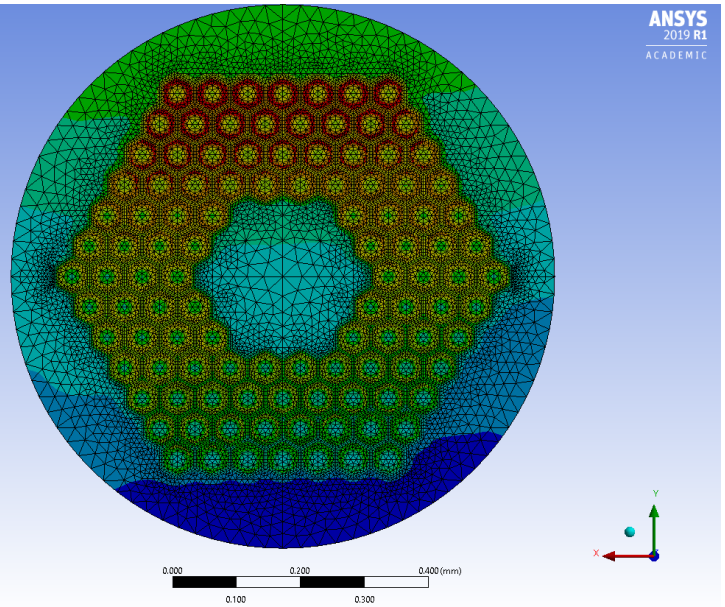


FLUKA Model

Thermal Evolution

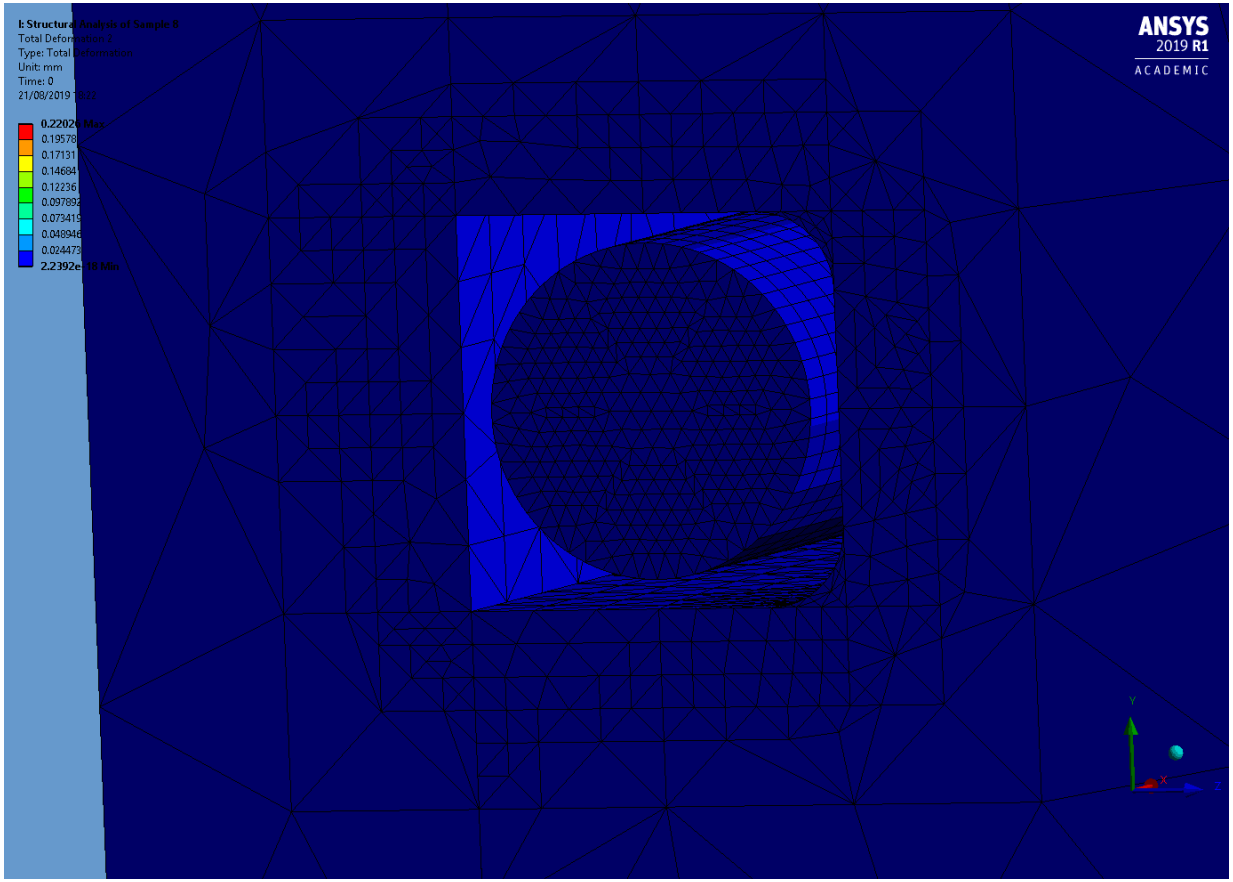


Temperature Distribution in Sample Holder
right after Beam Impact

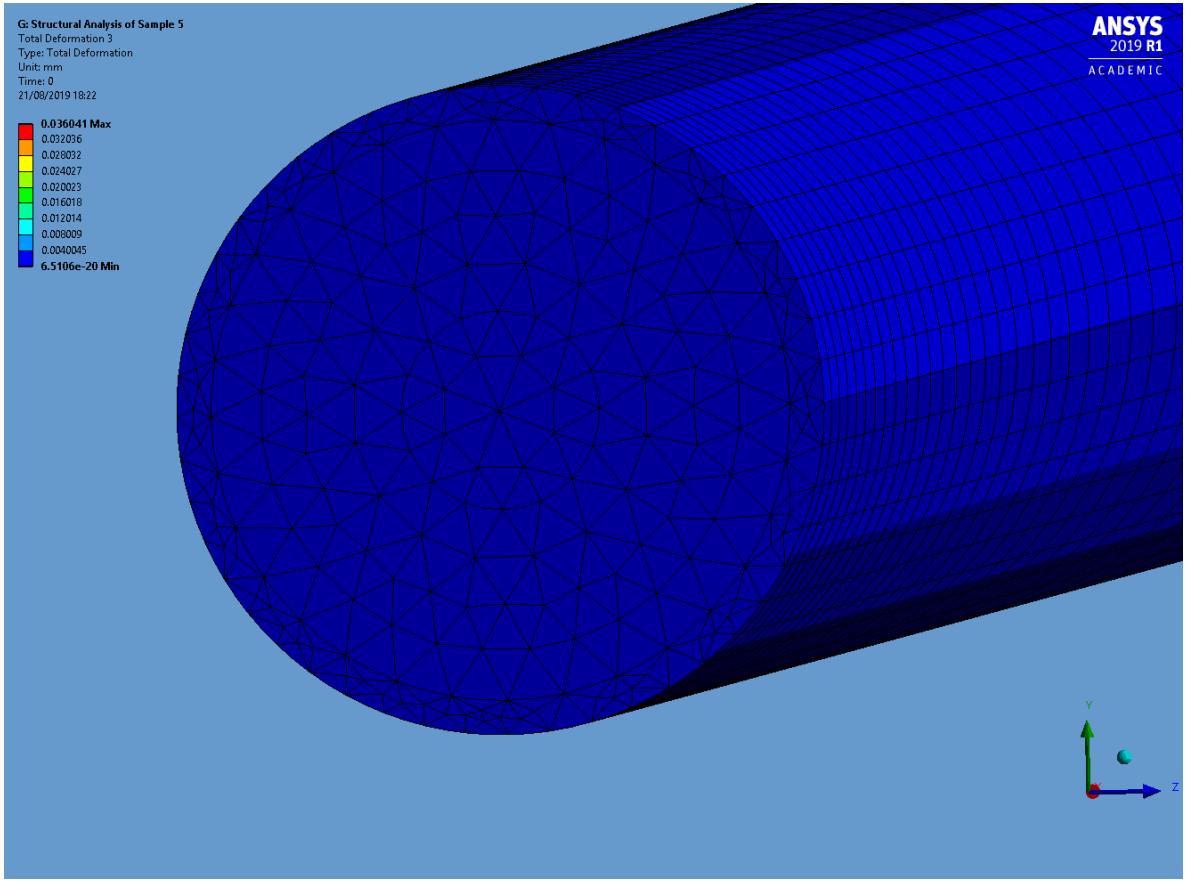


Temperature Distribution in Detailed Strand
right after Beam Impact

Mechanical Response



Mechanical Response

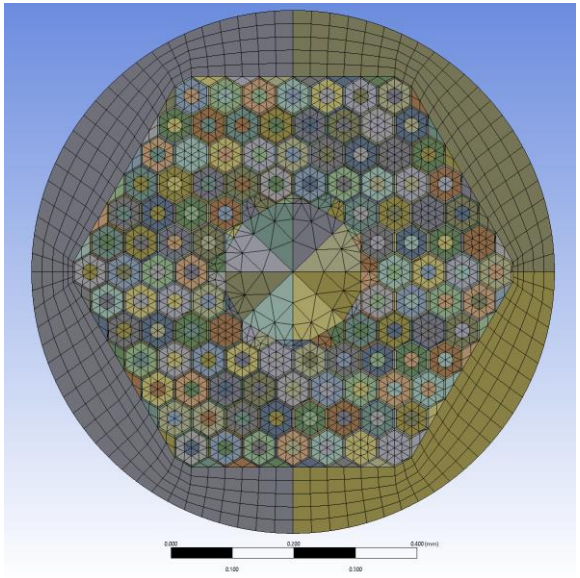


Mechanical Response

Allowed for quantitative results such as:

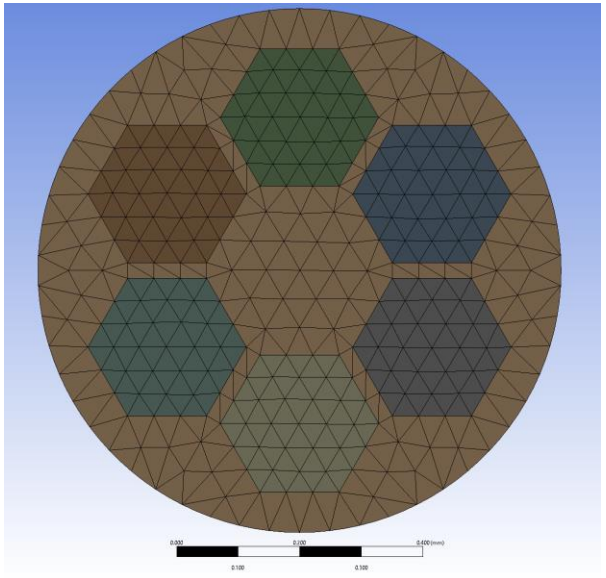
- Importance of placement in the Strandholder
- Strain induced bending of the Strands and their movement during the Reaction

Different Models



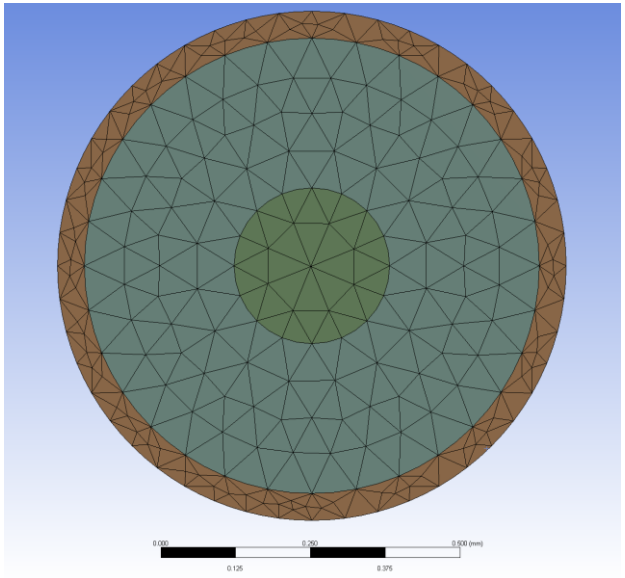
Maximum Detail Model:

- Fully elastic Nb_3Sn
- Plastic fully annealed Cu



Nb_3Sn Cluster Model:

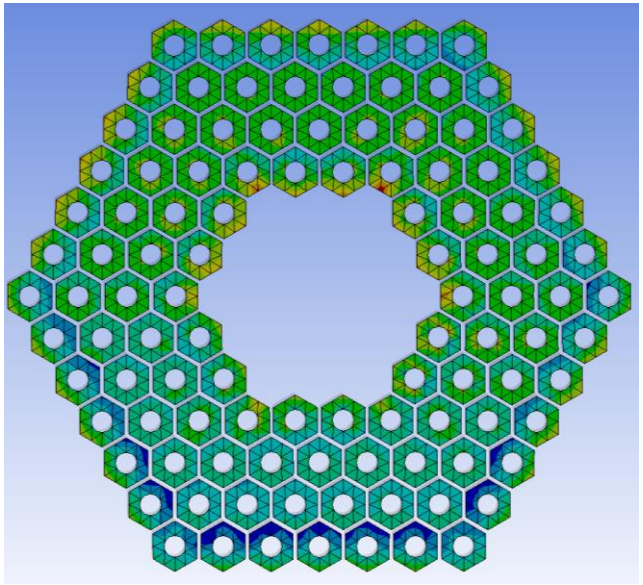
- Absolute area of Nb_3Sn preserved
- Plastic behavior for Nb_3Sn
- Plastic fully annealed Cu



Cylindrical Shell Model:

- Plastic composite Material of Nb_3Sn and fully annealed Cu
- Plastic fully annealed Cu

Mechanical Response



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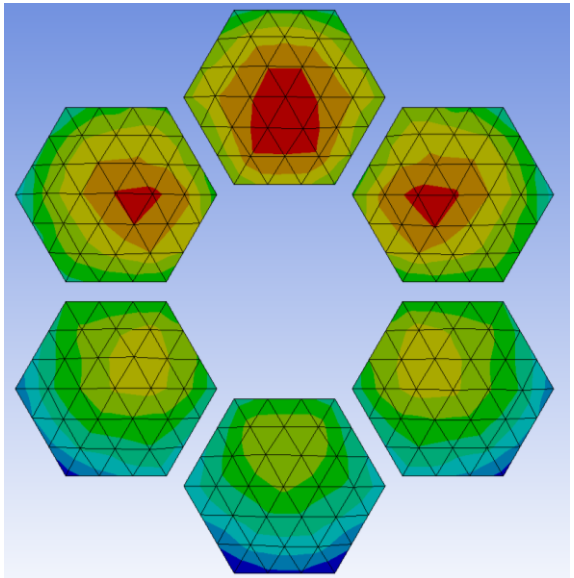

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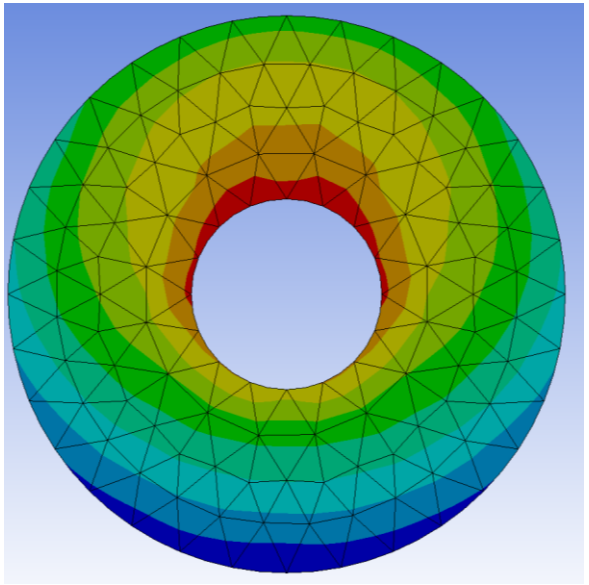

Cylindrical Shell Model:

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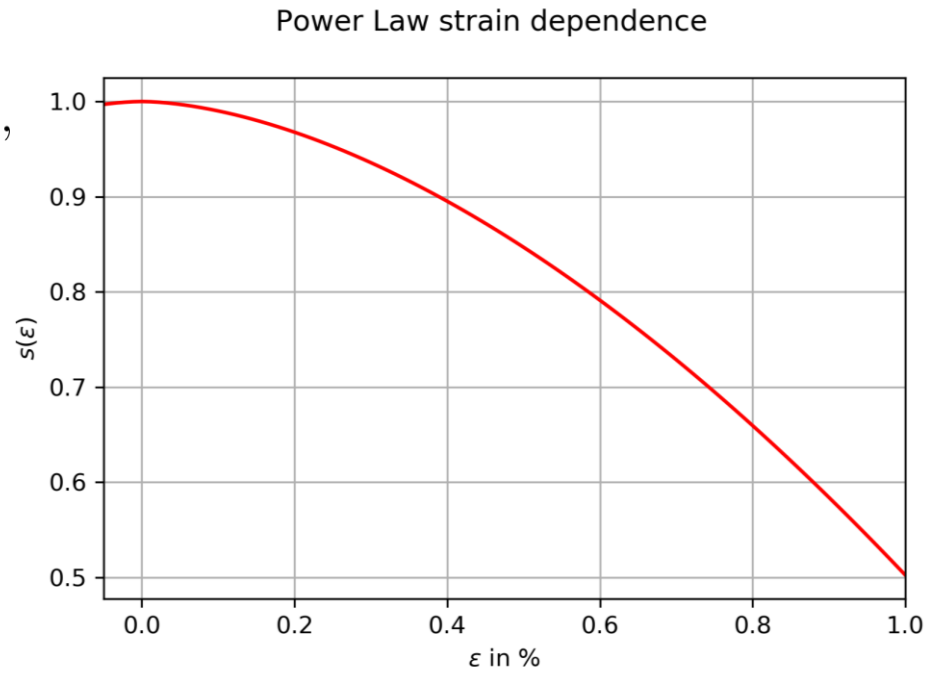
Theory based Evaluation

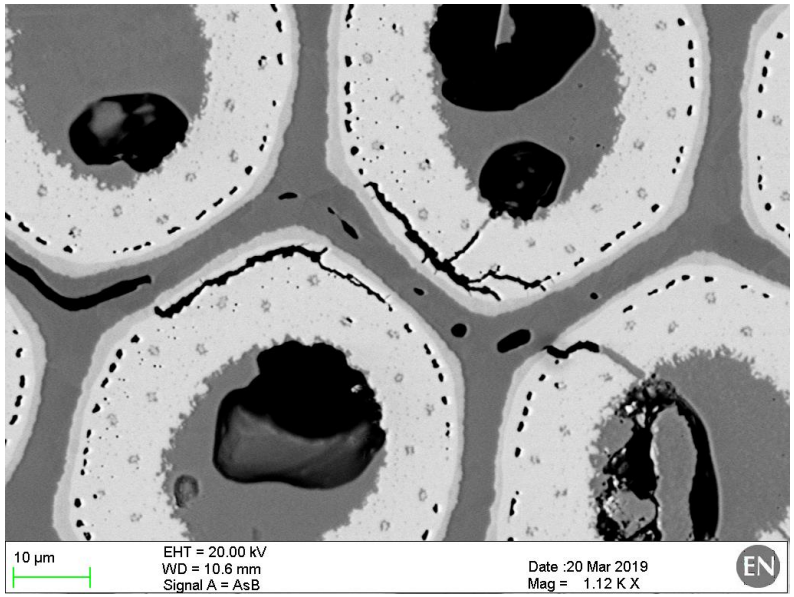
Strain Dependency

$$
\begin{aligned}
J_c(B,T,\varepsilon) &= C_1\ (1-t^2)\ b^{-0.5}\ (1-b)^2, \\
t &= \frac{T}{T_c \cdot s(\varepsilon)^{\frac{1}{3}}}, \\
b &= \frac{B}{B_{c2}(T,\varepsilon)}, \\
B_{c2}(T,\varepsilon) &= B_{c2,0} \cdot (1-t^{1.5}) \cdot s(\varepsilon)
\end{aligned}
$$

MAG - Scaling Law



Filament Cracking

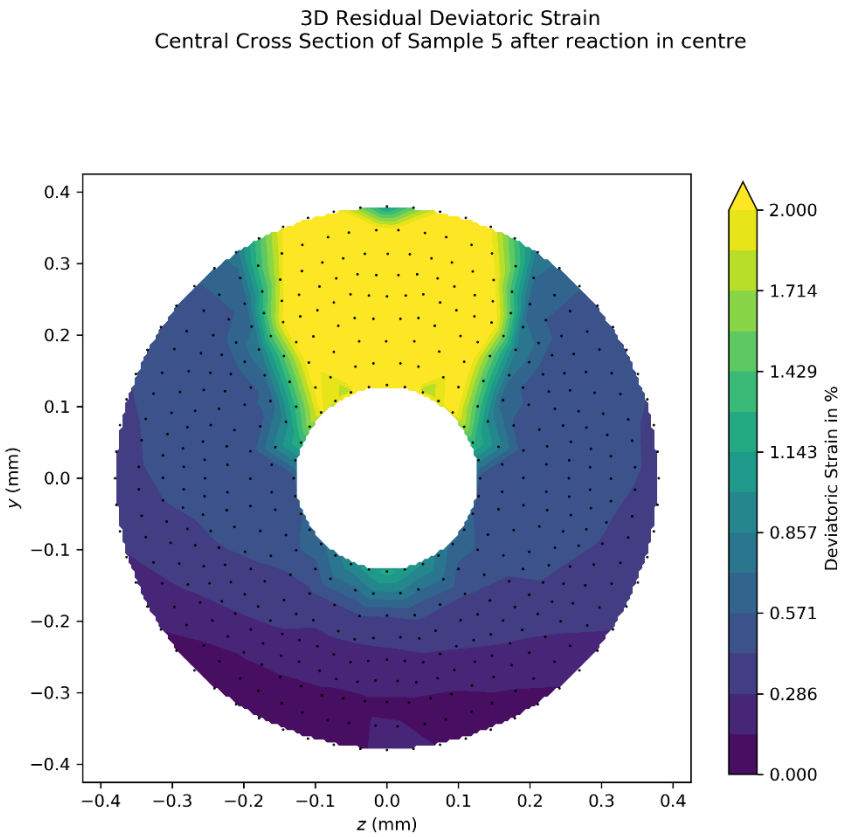


- Highly dependent on the local composition
- Is a filament dead when it has cracks?

-> Irreversibility Cliff

->rather than a strict limit
Fundamental Difference to Strain Scaling Law

Post Processing



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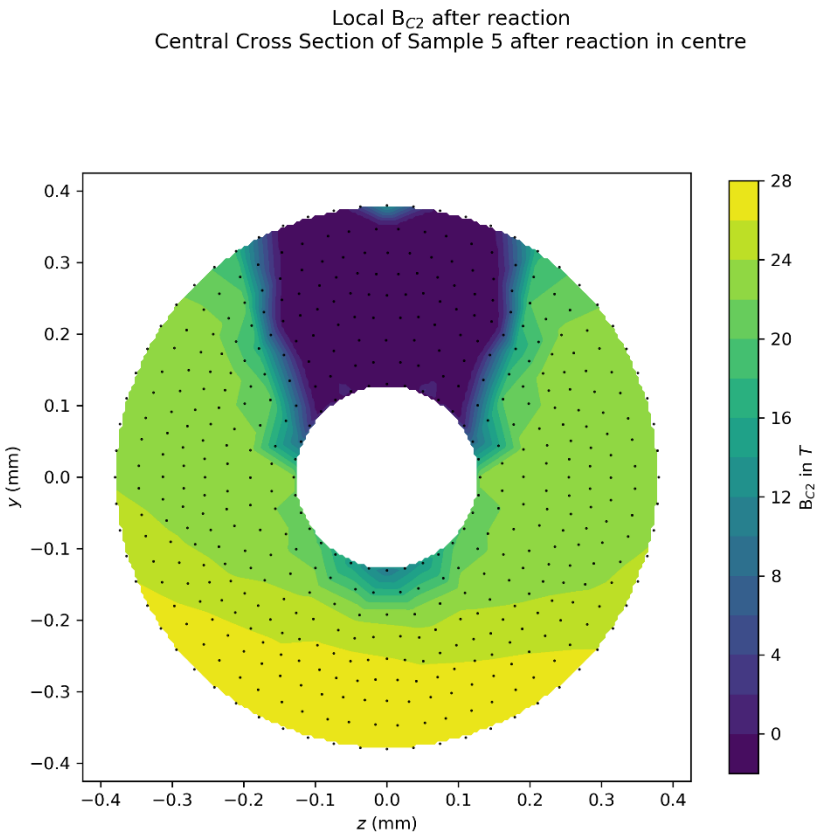

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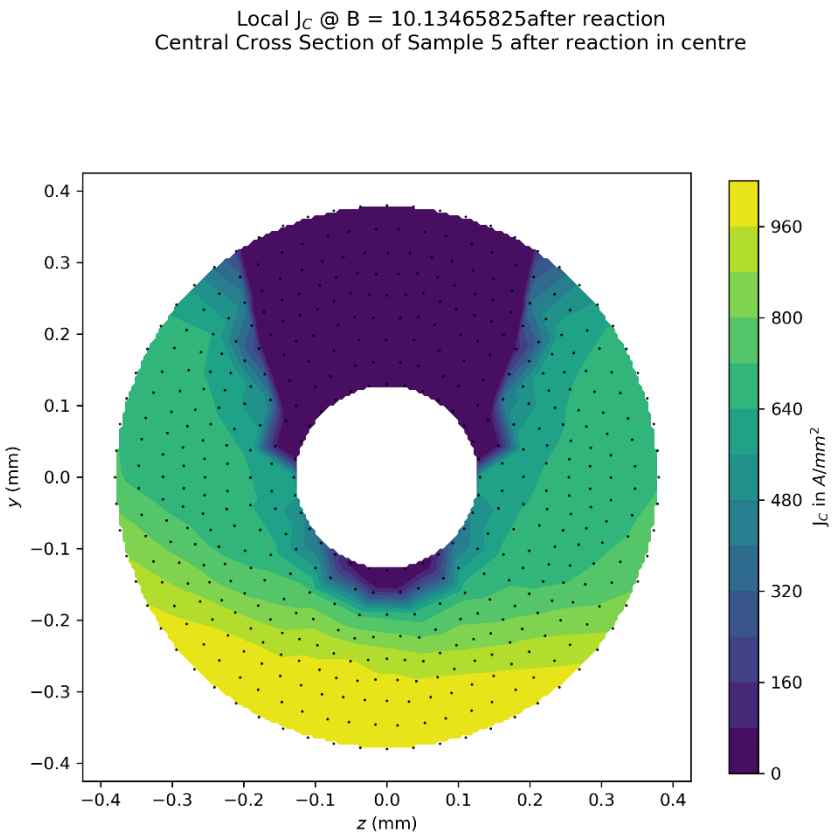

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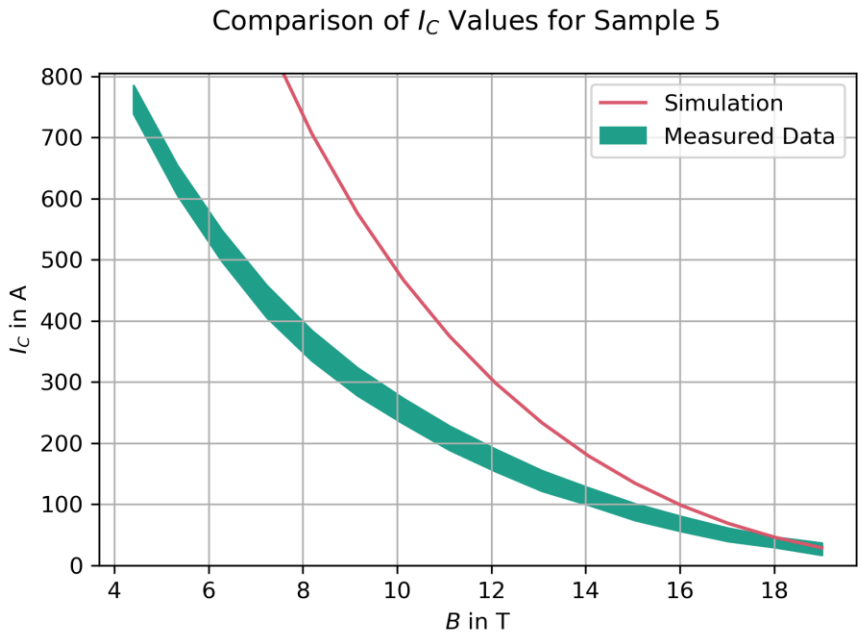
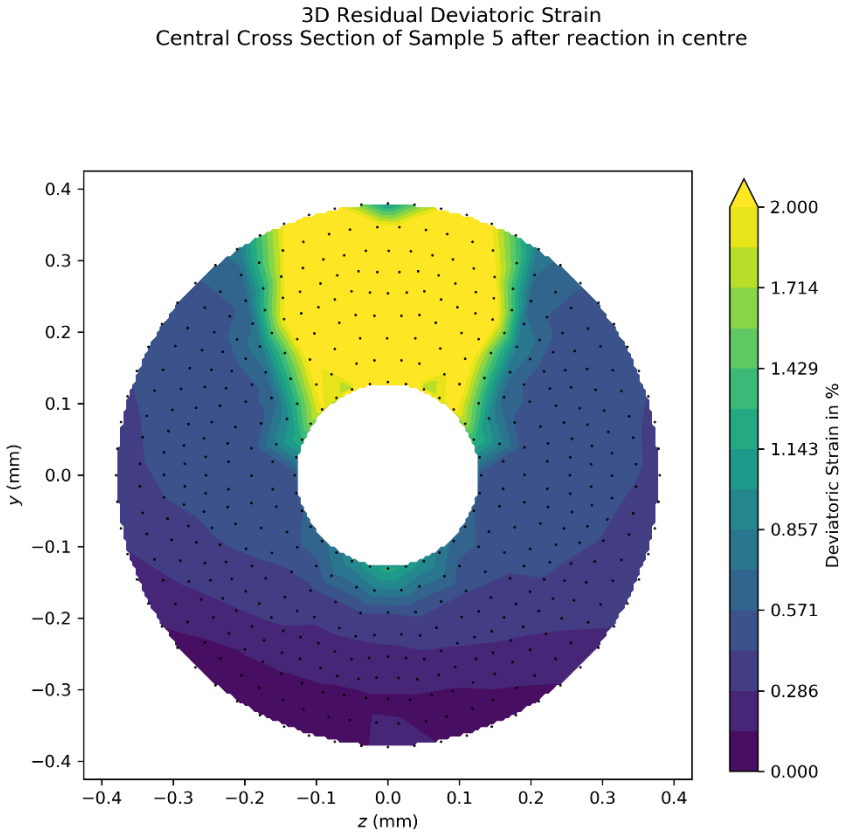
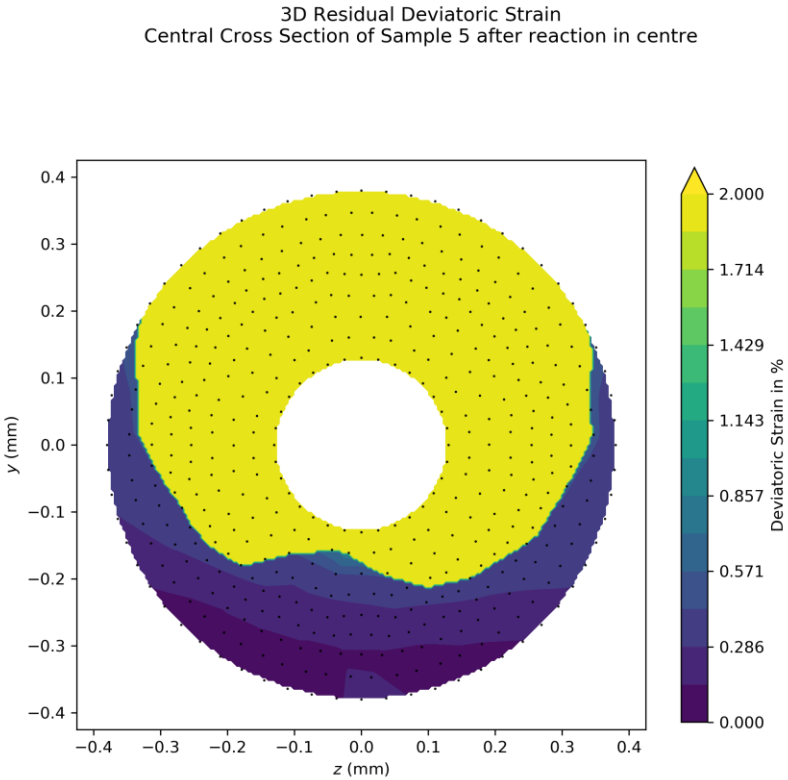


Now Let's introduce Filament Cracking

Post Processing

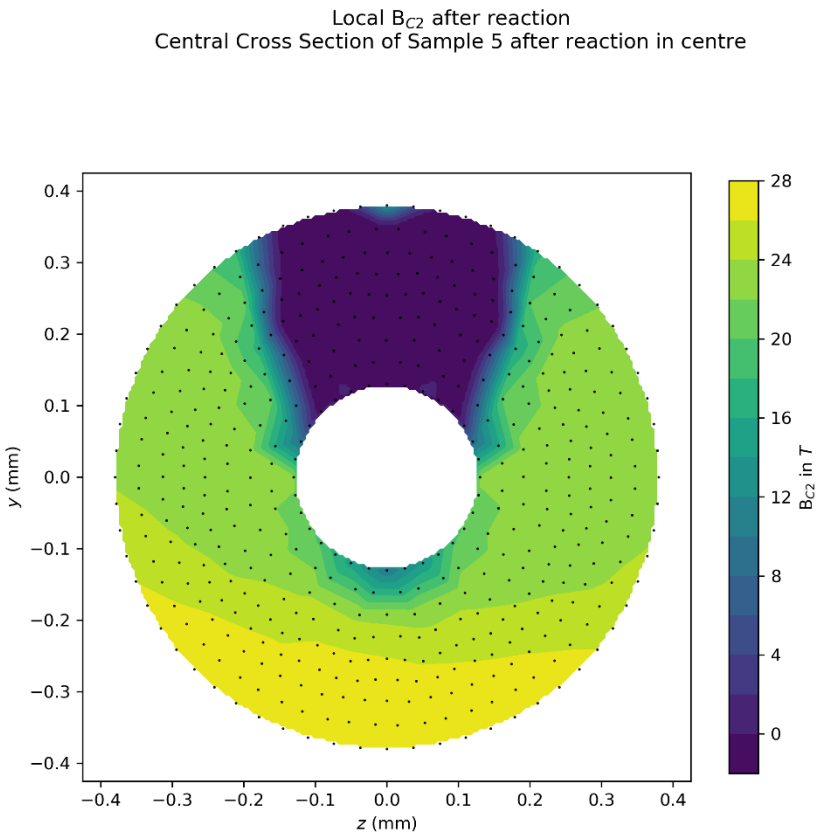


Cracking Disregarded

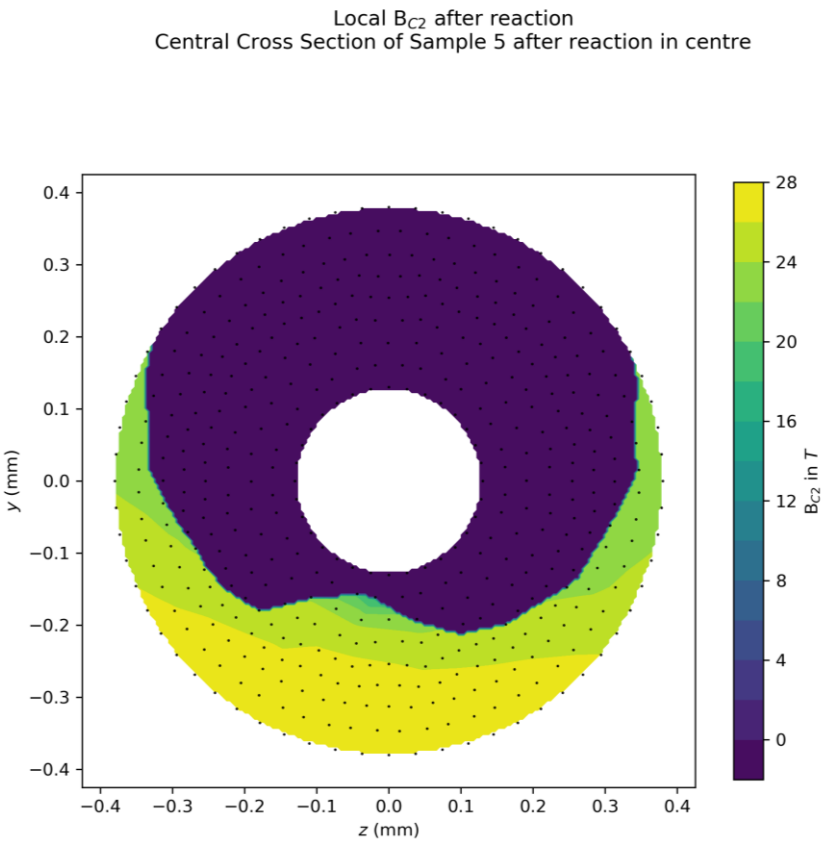


Cracking from .26%

Post Processing

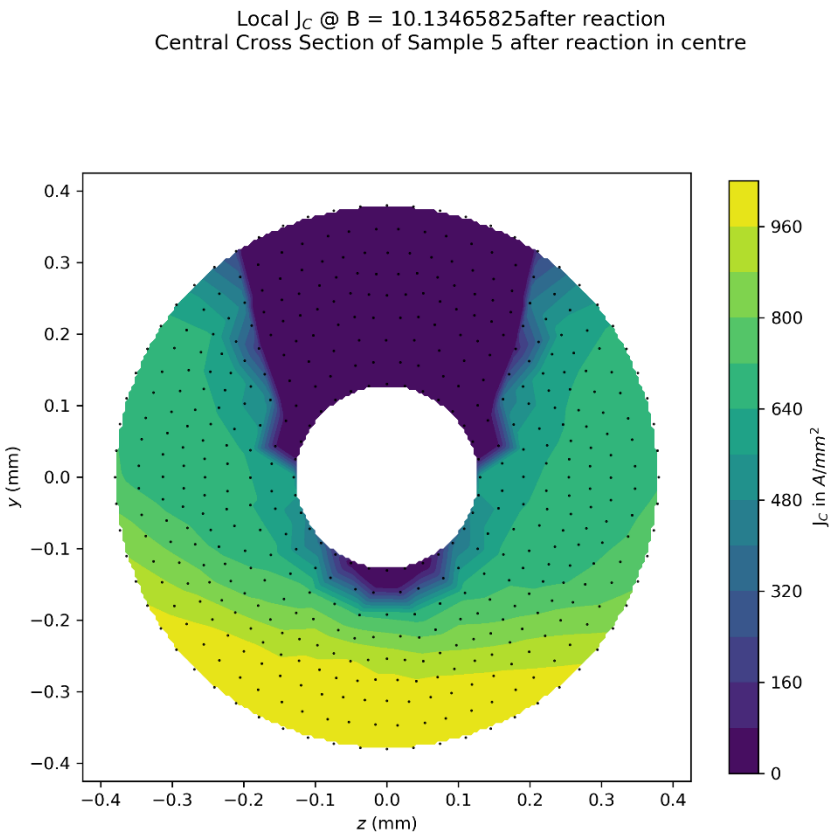


Cracking Disregarded

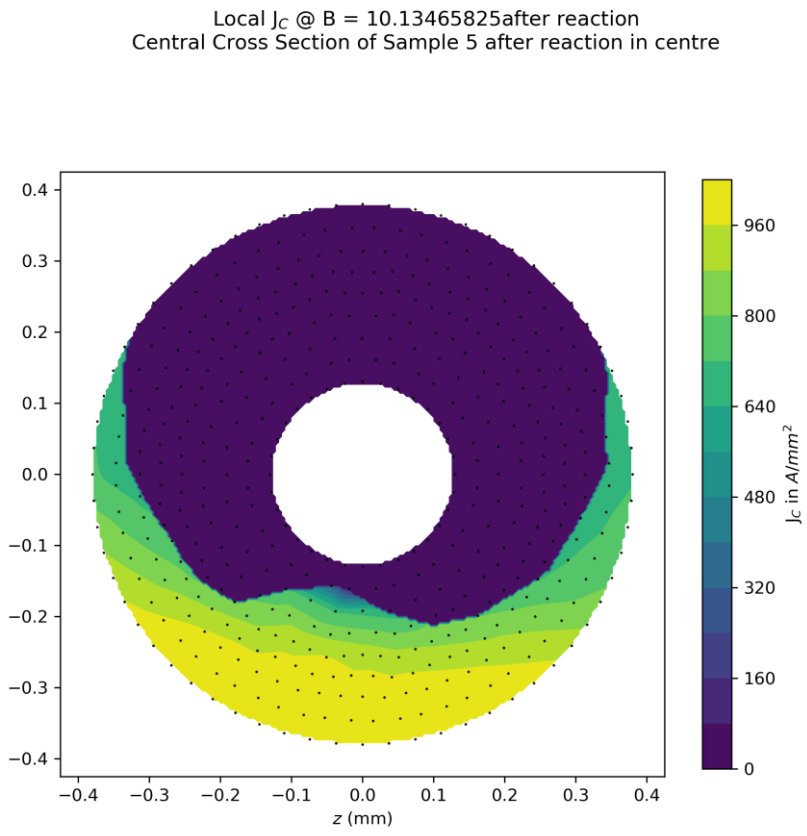


Cracking from .26%

Post Processing



Cracking Disregarded



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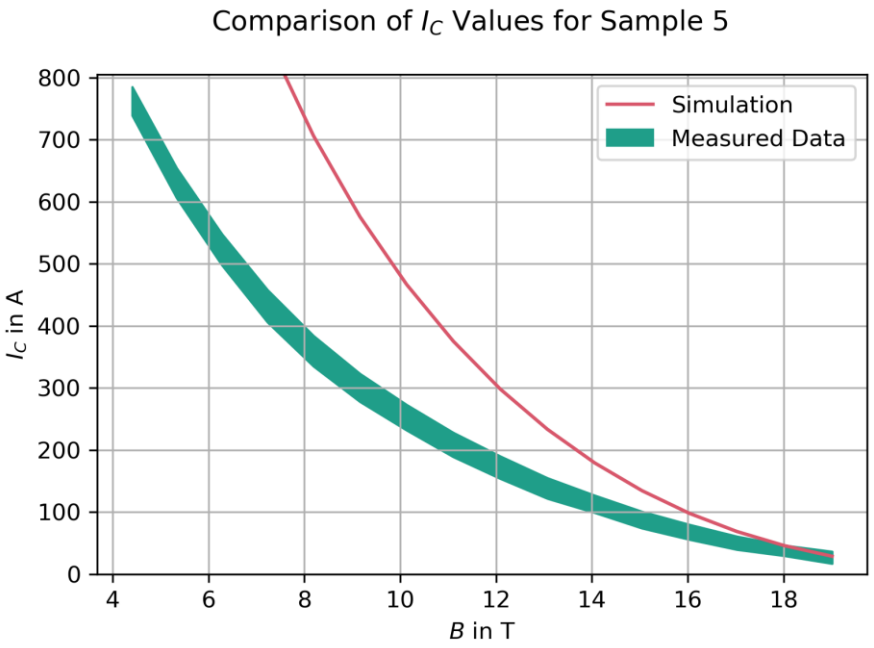
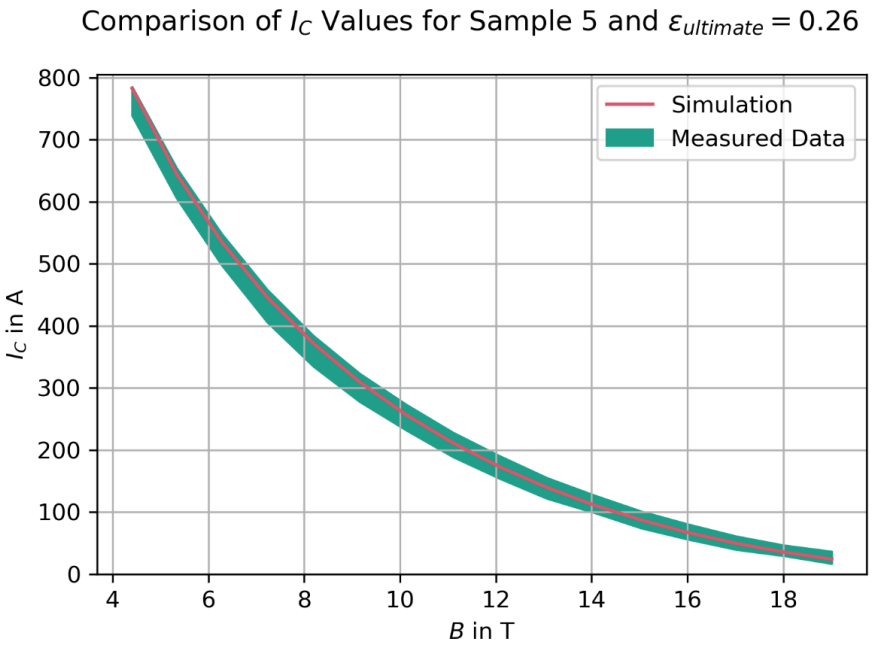
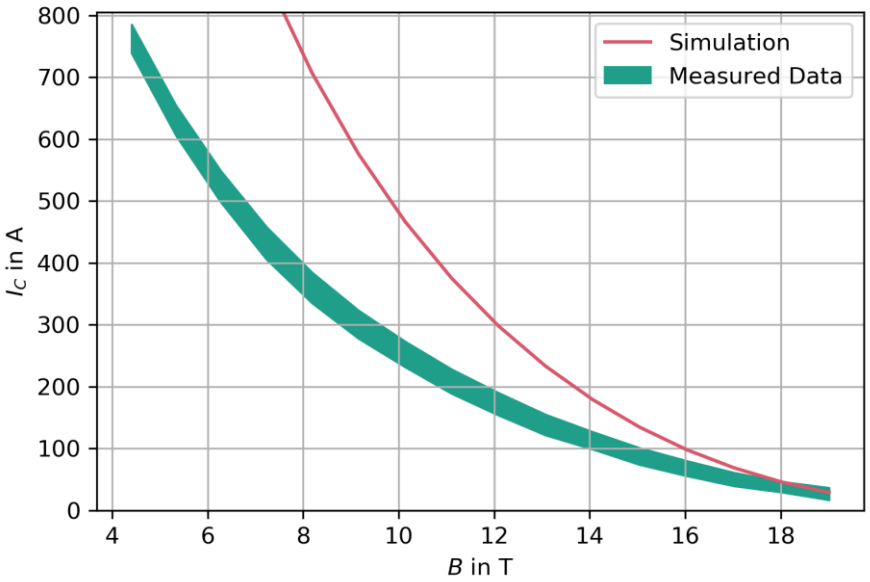
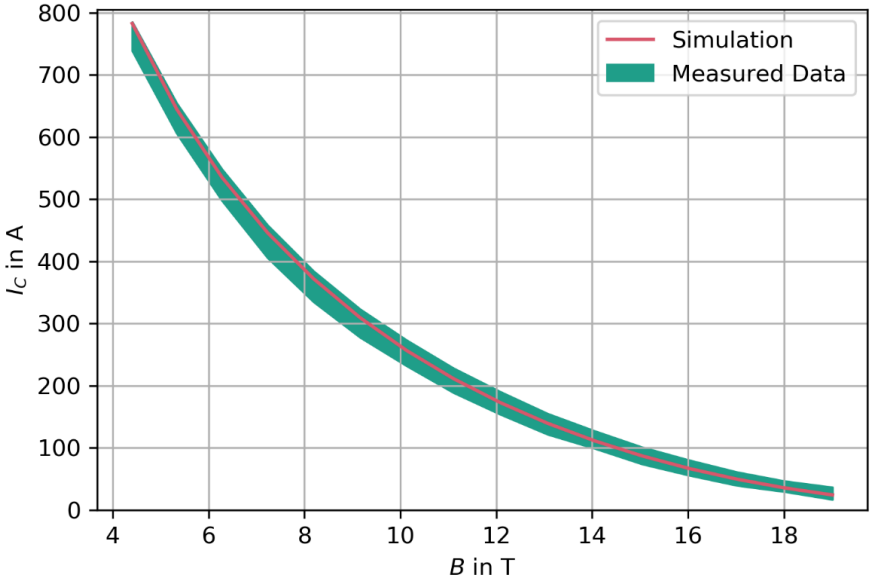


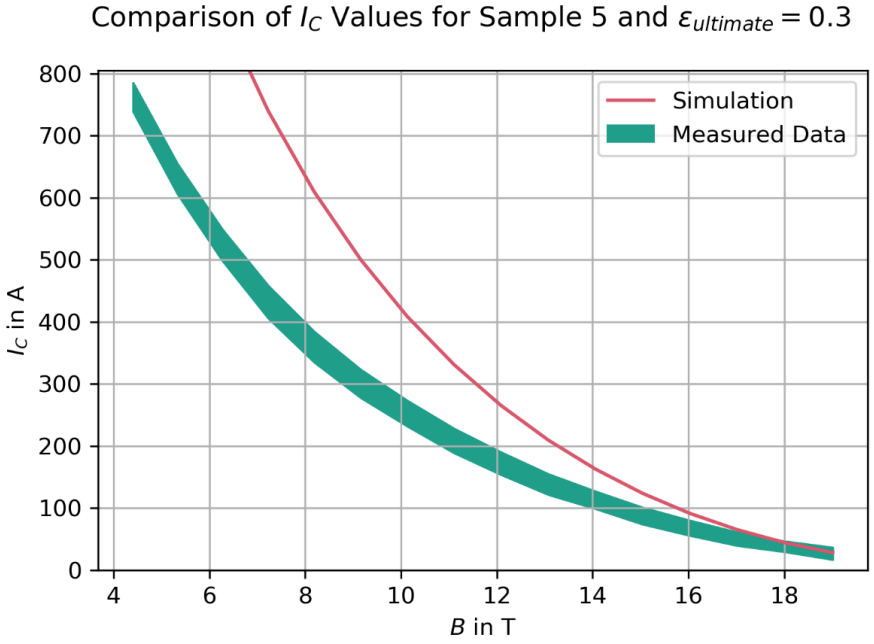


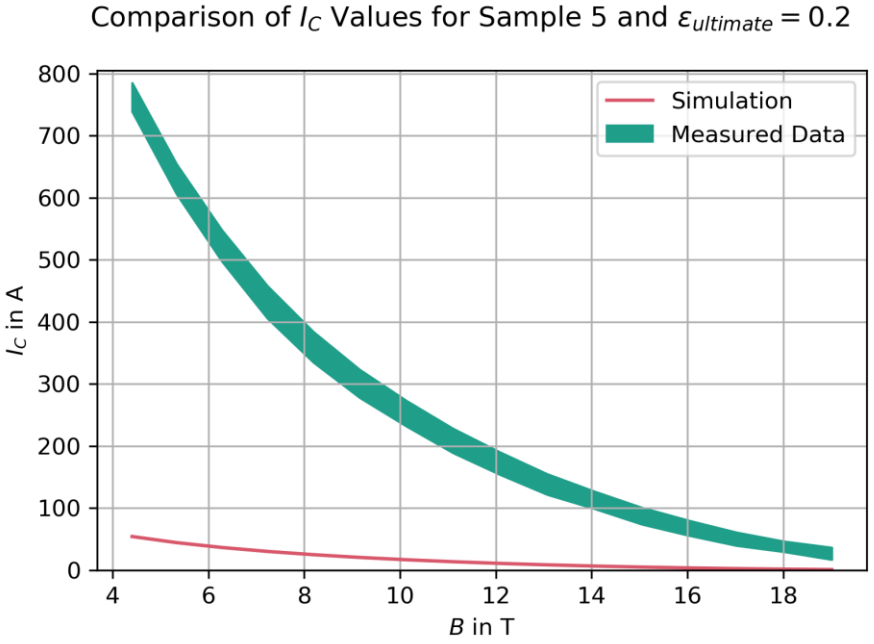
Cracking Disregarded

Cracking from .26%

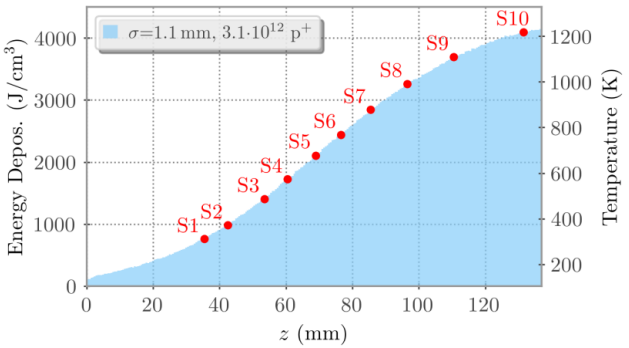

Comparison of I_C Values for Sample 5
Simulation
Measured Data
I_C in A
B in T
0
100
200
300
400
500
600
700
800
4
6
8
10
12
14
16
18


Comparison of I_C Values for Sample 5 and $\varepsilon_{ultimate} = 0.26$
Simulation
Measured Data
I_C in A
B in T
0
100
200
300
400
500
600
700
800
4
6
8
10
12
14
16
18

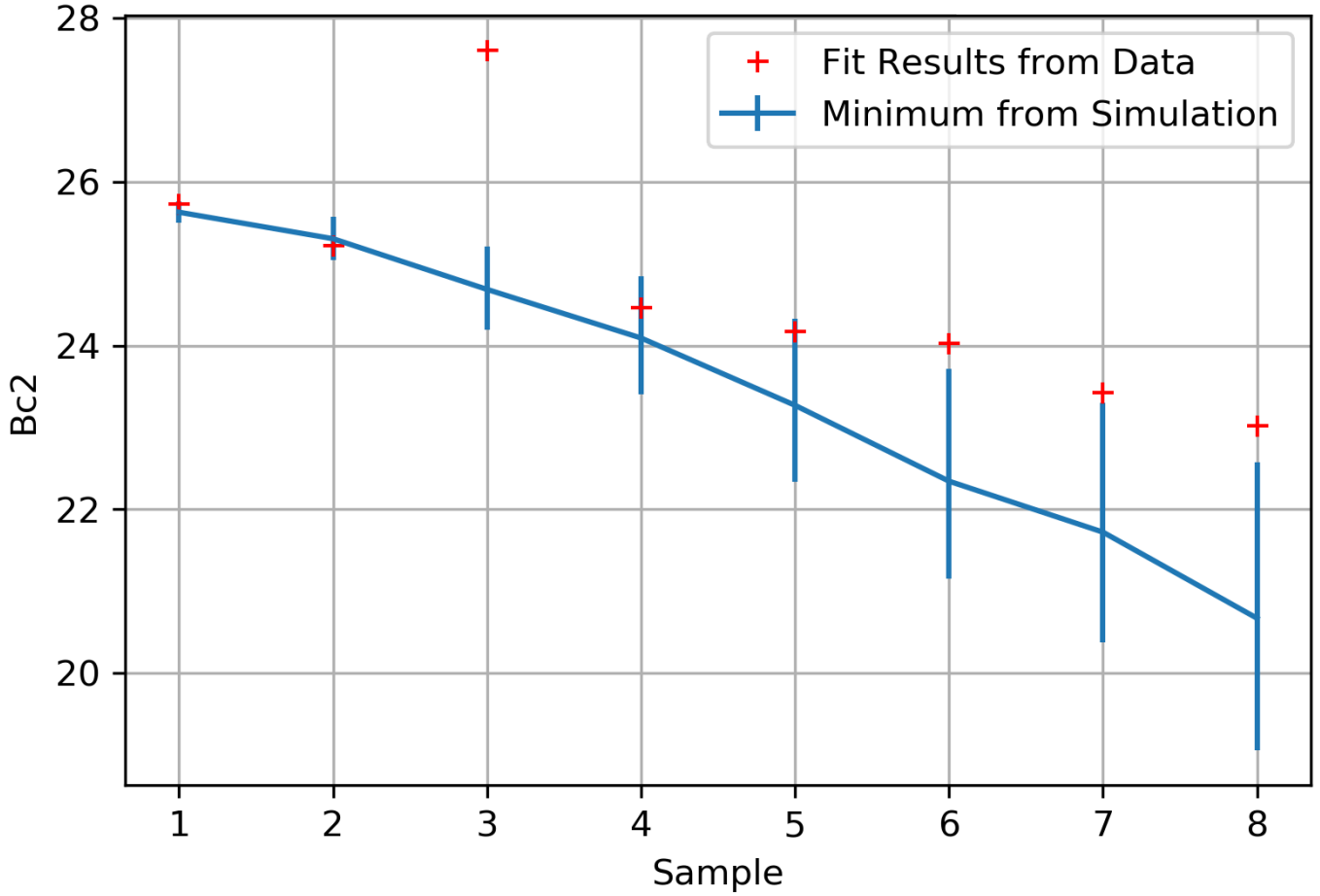

Comparison of I_C Values for Sample 5 and $\varepsilon_{ultimate} = 0.3$
Simulation
Measured Data
I_C in A
B in T
0
100
200
300
400
500
600
700
800
4
6
8
10
12
14
16
18


Comparison of I_C Values for Sample 5 and $\varepsilon_{ultimate} = 0.2$
Simulation
Measured Data
I_C in A
B in T
0
100
200
300
400
500
600
700
800
4
6
8
10
12
14
16
18

Results



B_{C2} degradation

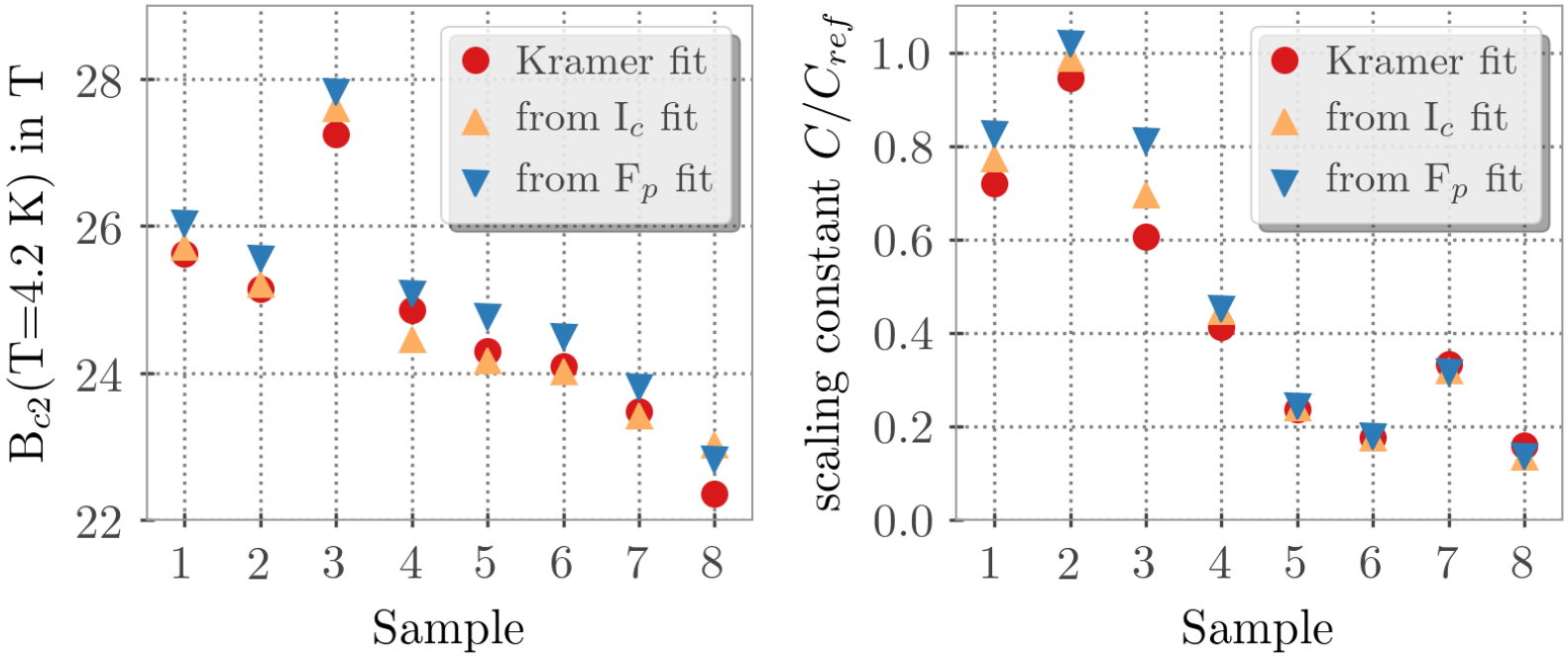


Results

We were able to qualitatively explain:

- The bending and marking of the Strands
- The nonlinear influences of the Sample Holder
- difference between I_C and B_{C2} degradation
- Inconsistencies in I_C degradation for high Sample numbers

Results



Fits on Measurement Data

Results

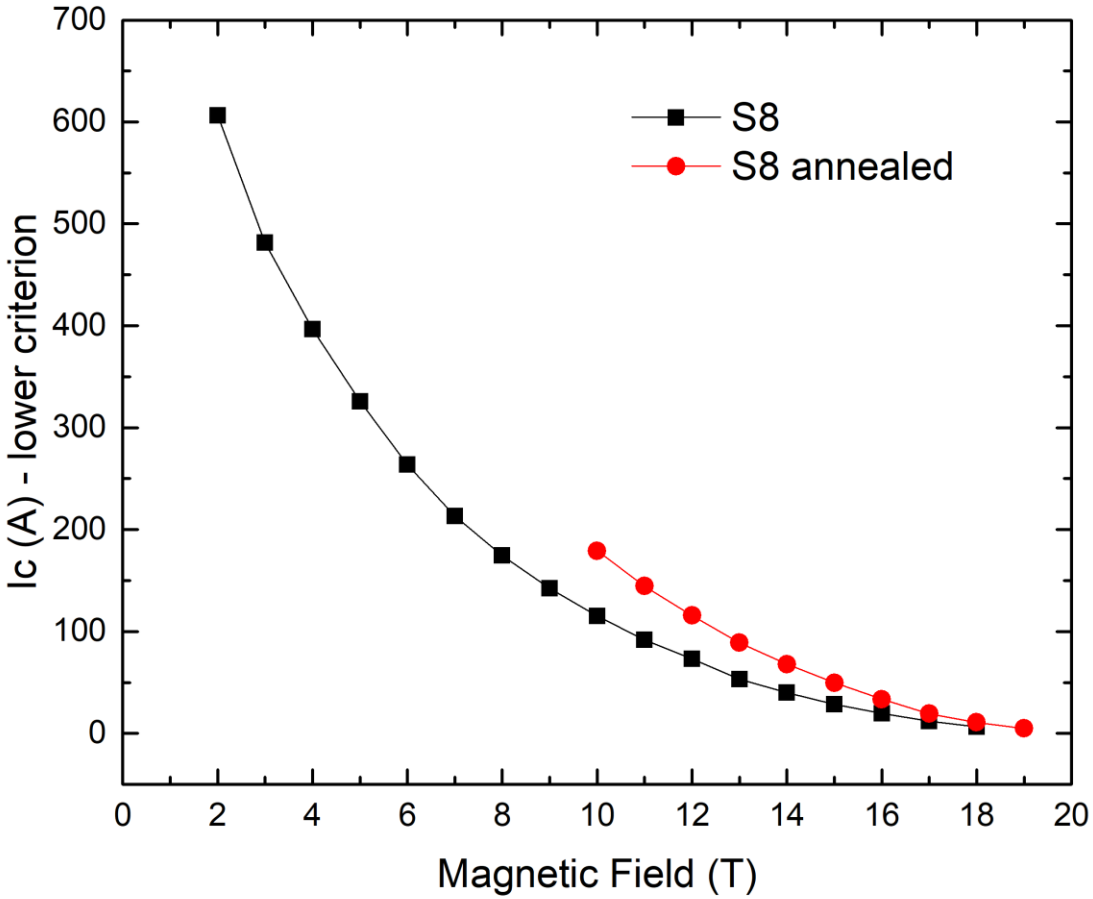
It was not possible to:

- Provide an Analysis tool to accurately predict the I_C degradation in areas of Large thermal gradients

We were able to predict:

- B_{C2} degradation tendencies of the Samples

Results



UNIGE Annealing Measurements

Conclusion

- We have modeled the experimental Set up
- We were able to identify the two main sources of degradation
- This was verified by the annealing experiment
- Still Model Based Predictions for future experiments remain a big challenge

Thank you for your attention.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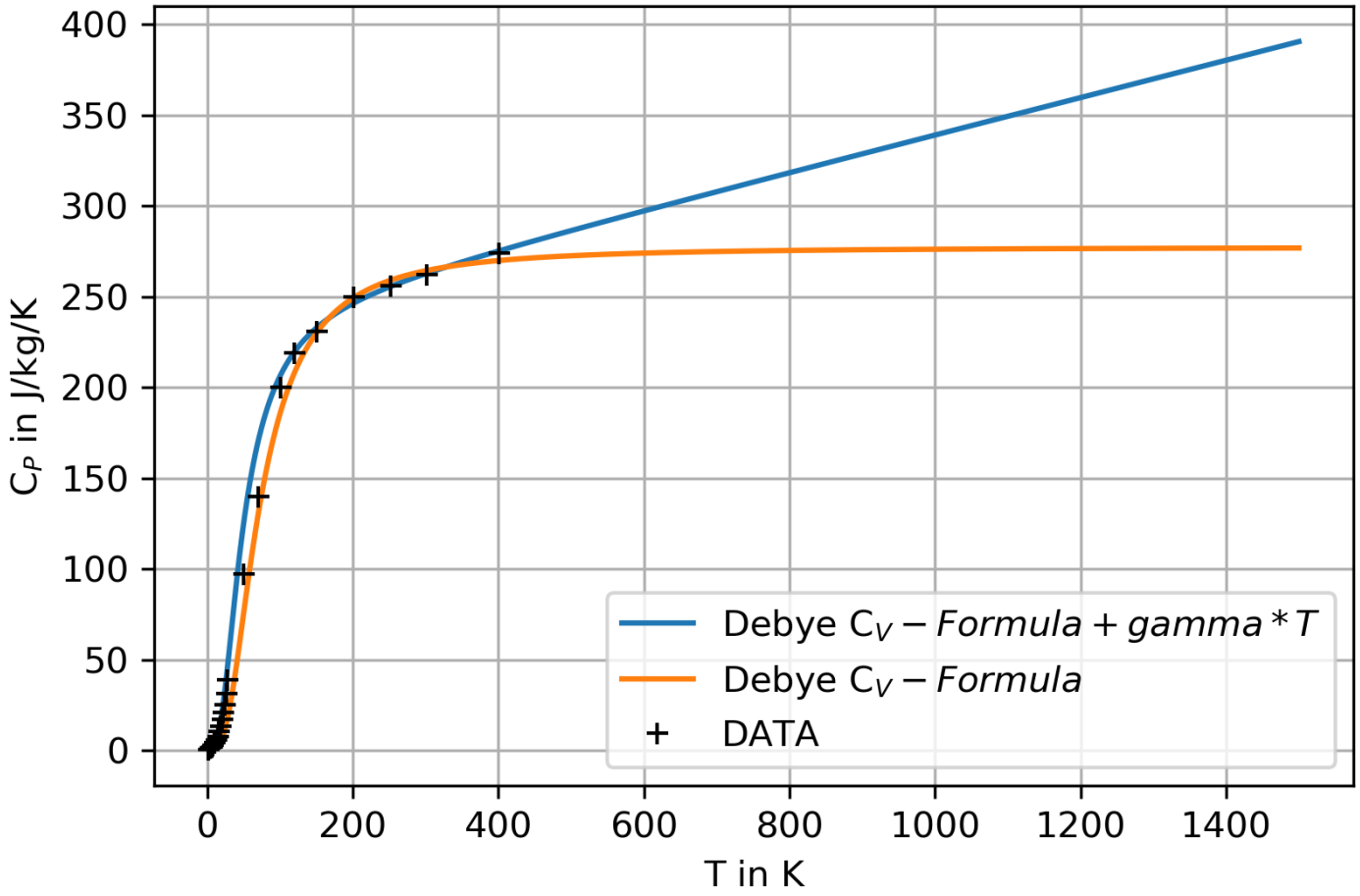
Backup Slides

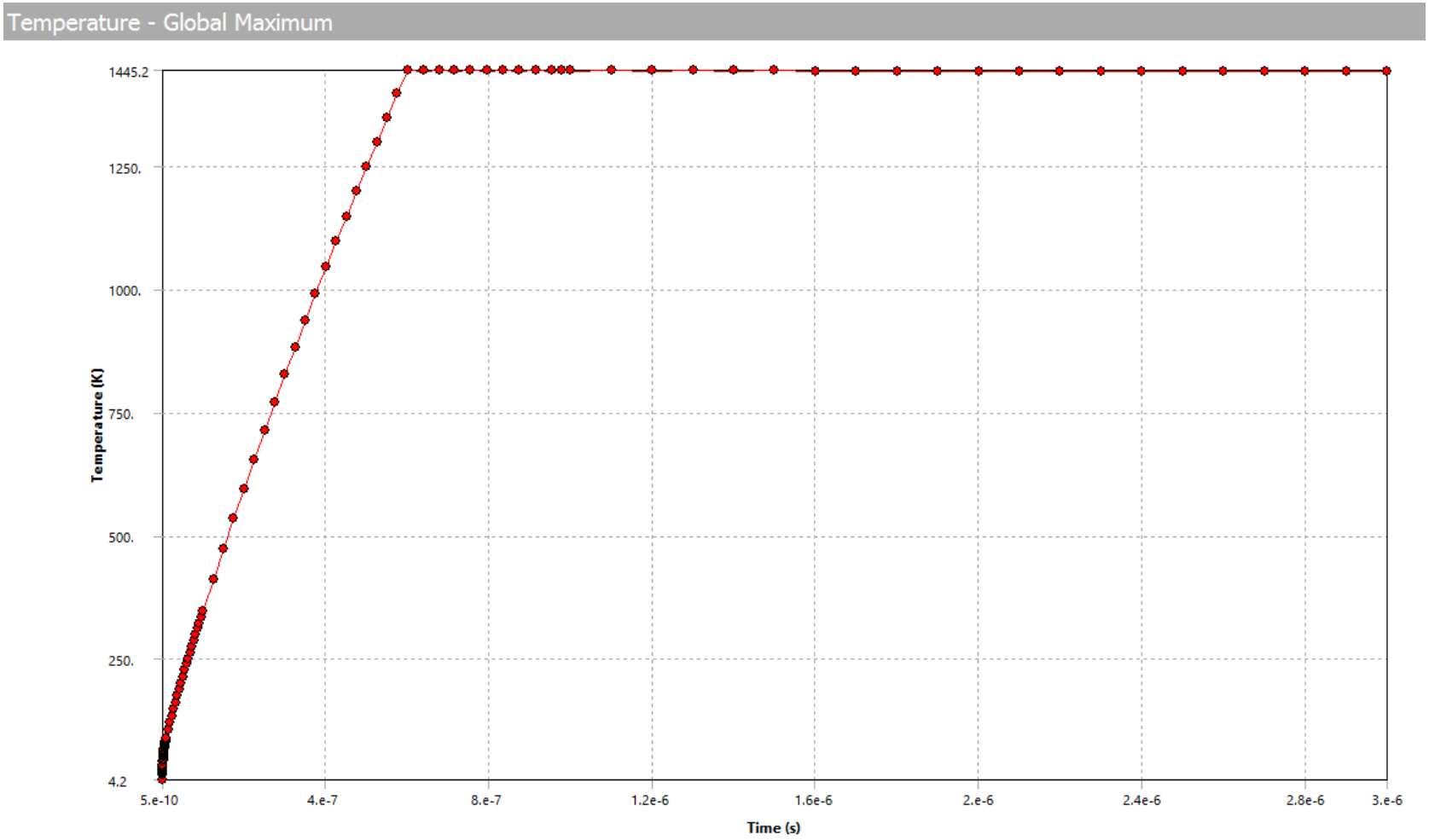
Discussion

- $\varepsilon_{ultimate}$ as a fit parameter cannot be found consistently for all samples, but with individual fits we can fit the measurements very well.
- The individual $\varepsilon_{ultimate}$ lie within a reasonable range of literature values and show a linear growth with Hotspot Temperature.
- Either this is physically relevant or a systematic error within the Analysis Model
(see B_{C2} Degradation Maybe Material Data for extreme temperatures?).

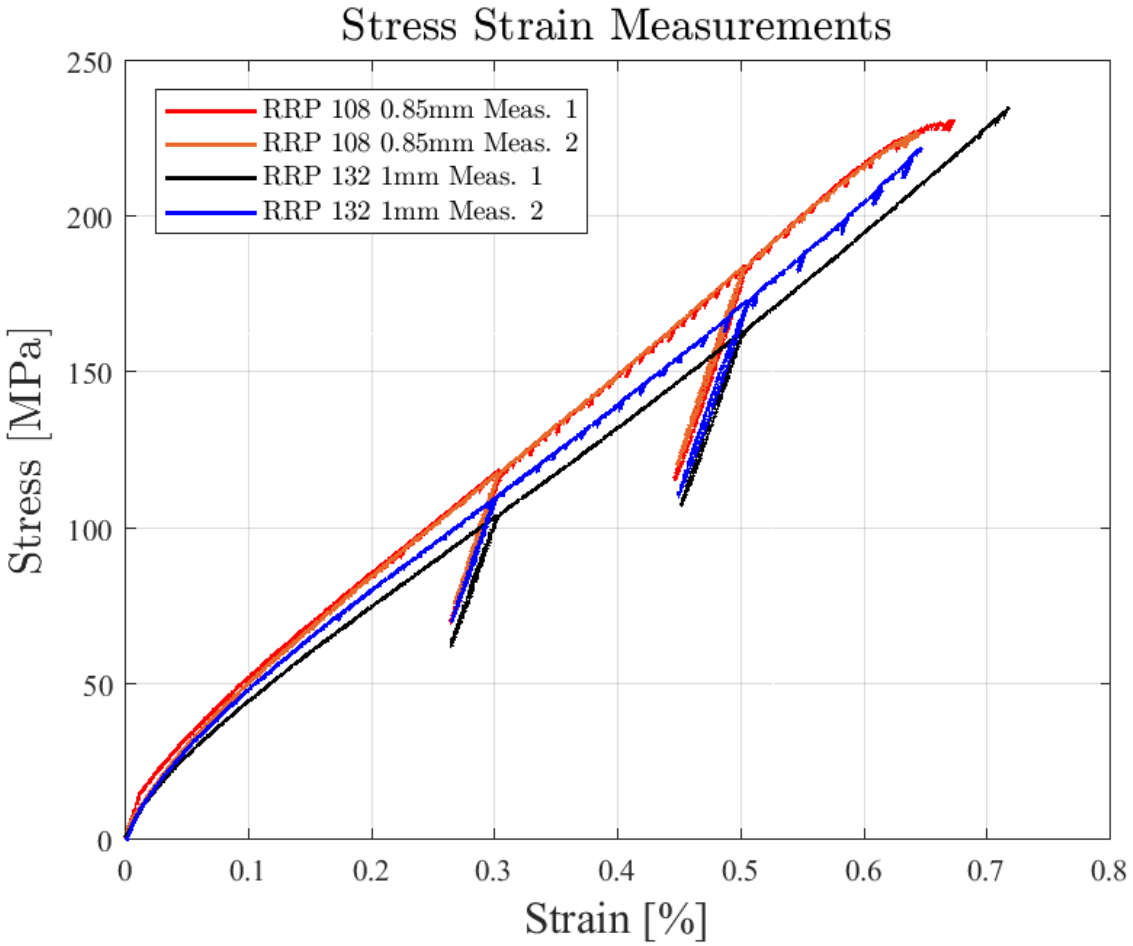
Nb_3Sn C_P


400
350
300
250
200
150
100
50
0
C_P in J/kg/K
0
200
400
600
800
1000
1200
1400
T in K
Debye $C_V - Formula + gamma * T$
Debye $C_V - Formula$
DATA

Temperature Evolution



RRP Stress-Strain Curve



José FERRADAS – Paris Nb3Sn Workshop